Source Direction Detection based on Stationary Electronic Nose System

Jie Cai, and David C. Levy

Abstract—Electronic nose (array of chemical sensors) are widely used in food industry and pollution control. Also it could be used to locate or detect the direction of the source of emission odors. Usually this task is performed by electronic nose (ENose) cooperated with mobile vehicles, but when a source is instantaneous or surrounding is hard for vehicles to reach, problem occurs. Thus a method for stationary ENose to detect the direction of the source and locate the source will be required. A novel method which uses the ratio between the responses of different sensors as a discriminant to determine the direction of source in natural wind surroundings is presented in this paper. The result shows that the method is accurate and easily to be implemented. This method could be also used in movably, as an optimized algorithm for robot tracking source location.

Keywords—Electronic nose, Nature wind situation, Source direction detection.

I. INTRODUCTION

TODAY electronic nose are widely used in food(beverage) quality industry, pollution control and fire detection [1-8]. The techniques for signal processing in ENose, including signal restoration, feature extraction and classification, are very well developed [9-15]. Additionally, those techniques are able to give some other measurable information, such as concentration, which could be used to locate the emission source [16] or give the direction where the "smell" comes. Obviously the direction could be derived when the source is located. Normally, source localization is performed by the cooperation of electronic nose and mobile vehicles since robotic techniques are getting mature [17-19]. However problem could occurs during the specific situations, such as instantaneous emission and complex landscape environment. In these cases, mobile sensors could not perform the task properly. Thus, an interesting for the stationary sensors to locate the source and detect the direction of source arises.

There are few publications is about source localization with stationary sensors. Jorg Matthes provided an approach to locate the source and direct the source with spatially distributed electronic noses [16], but it is costly to construct a such electronic noses network. In addition, Jorg's approach only considered normal diffusion and advection, that Jorg's approach is not able to solve a crosswind or break wind situation.

In this paper, a method of stationary sensors to detect the direction of emission source within natural wind surroundings is presented. In section II, the whole experimental ENose system is introduced. A new approach is presented in section III, which will be divided into two aspects: (1) determine the direction of source with given axis of my ENose system by analysis the response of sensors in advection situation; (2) in crosswind situations the direction of source detection. Break wind cases will be discussed in section IV. Experimental and resulted is presented in section V, afterwards the conclusion is drawn in section VI.

II. SYSTEM CONSTRUCTION

My electronic nose system is build up by four sensors which are separated by a square impermeable separator with four wings. Fig. 1 shows the structure of the system, cross wind direction and speed ($V_{CrossWind}$) could be presented as the sum of x direction vector (V_x) and y direction vector (V_y). Angle α is used to denote the direction of crosswind. The shape of sensors is considered as a circle with radius 0.5cm. The dimensions of separator are 2cm X 2cm for square and each wing has included angle 45^0 with length $2\sqrt{2}$. To make an assumption, we treat the source is placed on an impermeable z=0 surface, thus the whole system is reduced the dimensions from 3 to 2. Position of emission dot source is unknown.

Angle θ presents the included angle of the axis of ENose system and connection line of emission dot source and center of ENose system. The direction of emission dot source is unknown, which is denoted by θ.
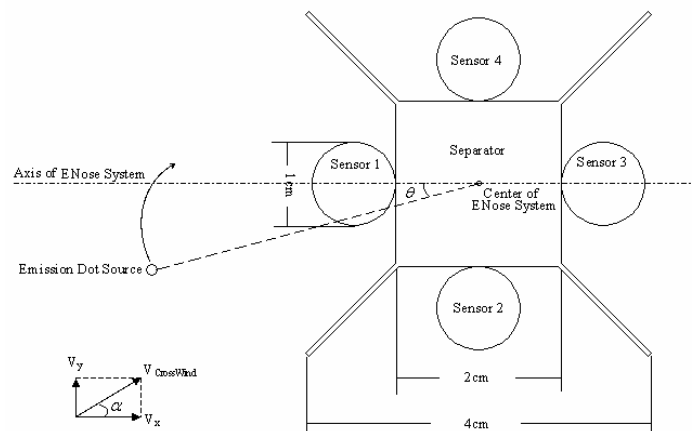

Fig. 1 Electronic nose system structure

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III. METHOD

In this section, the method to determine the source direction is given in two different cases, advection case and crosswind case. The solution for the source direction angle θ is given in both cases. In crosswind case, solution of θ could be derived from the advection case, θ is presented as a function of wind direction α and peak point angle θ_p.

A. Determine the Direction of Source to Center of ENose System in Advection

A series of simulation is done to analysis the relation between source direction angle θ and sensors responses. Fig. 2 shows the relations between angle θ and sensors responses, which are considered in the advection situation with V_x wind, randomly picked 5m/s.
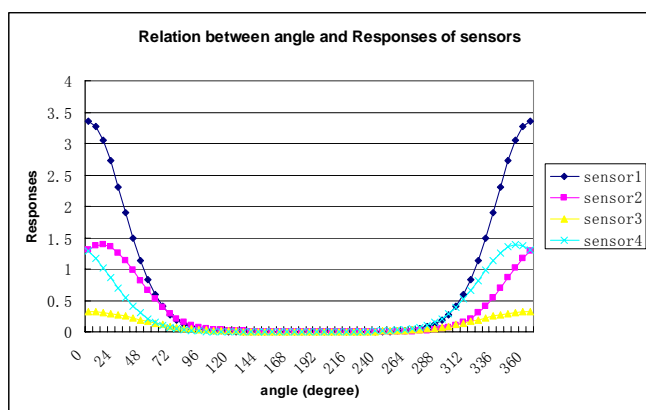

Fig. 2 Relations between angle θ and sensors responses

In Fig. 2, responses of different sensors are presented with different legends. Sensor 1 has highest response. Response of sensor 2 and 4 are axis symmetry by angle=180^0. Response of sensor 3 could be ignored. Additionally, from Fig. 2 we could see that the responses of sensors are a periodic function of angle with period of 2π, when source rate and distance is treated as constants.

With the preparation simulation and analysis, the method is established. After analysis of diffusion-advection equation and simulations, we found that source rate and distance of the source will not affect the ratio of responses of different sensors.

First we define that C1, C2, C3, C4 is the measured concentration by sensor 1 to sensor 4. Fig. 3 shows that the curve C2/C1 and C4/C1. It generated from the raw data of Fig. 2, we could not distinguish the value for sensors when the source direction is between 100^0 and 300^0 by eyes in Fig. 2, but Fig. 3 shows us clearly the relationship of sensors' response between 100^0 and 300^0. We could easily find that C2/C1 and C4/C1 are axis symmetry by angle=180^0, also the curve could be curvefit by Matlab. For C2/C1, the fitted equations could be present in Gauss3 equation format:

$$f(\theta) = 2.061 \cdot e^{-\left(\frac{\theta-154}{51.63}\right)^2} + 1.095 \cdot e^{-\left(\frac{\theta-107.9}{101.7}\right)^2}$$
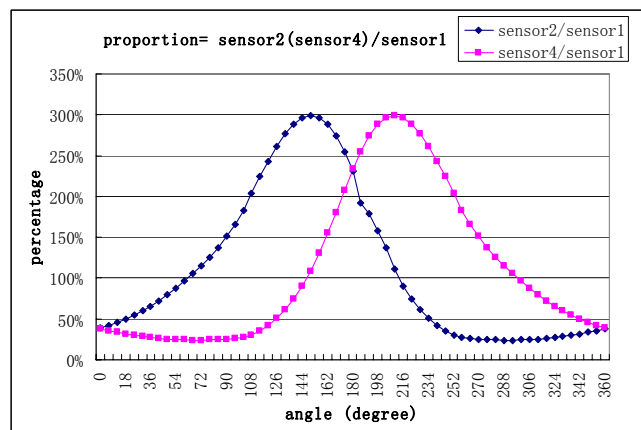$$+ 0.6291 \cdot e^{-\left(\frac{\theta-501.5}{191.2}\right)^2} \tag{1}$$

Fig. 3 Ratio of C2/C1 and C4/C1

Thus, the angle θ could be determined by calculating the ratio C2/C1 and C4/C1, then if C4/C1 is smaller than C2/C1, θ would between 0° and 180°, otherwise, θ would between 180° and 360°.

$$\theta = f^{-1}(\theta) \tag{2}$$

Equation (2) is the function to calculate angle θ, which is the solution for source direction.

B. Crosswind Case Direction Detection

In this case, the crosswind with V_x and V_y is applied. We randomly picked a set of speed for V_x and V_y, which is 5 and 3 respectively. A series of simulation is done to analysis this case. Fig. 4 shows the relations between angle θ and sensors' responses in the crosswind situation.
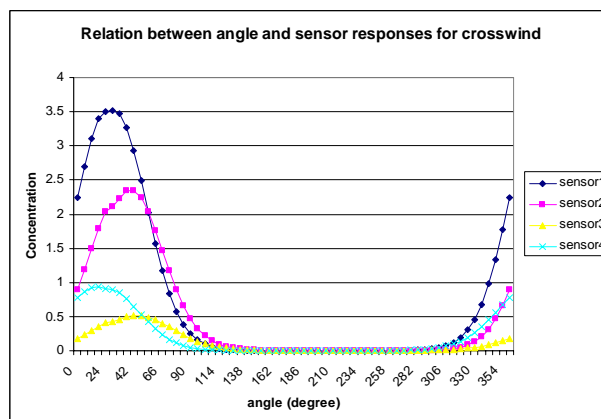

Fig. 4 Relations between angle θ and sensors responses for crosswind case

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We found that after a simple movement along angle axis to make the peak point starting the curve and connect the cut-off part to the end of curve a new figures shows in Fig. 5. After compare Fig. 5 and Fig. 2, we can find that the responses of sensors has similar pattern in both case.

Additionally, the ratio C2/C1 and C4/C1 in crosswind case has similar pattern as Gauss distribution, but we do not need to make any movement for the curve along angle axis. The ratio for sensor 2 and sensor 4 also has symmetry axis $\theta = 180^0$. Real line in Fig. 7 presents the ratio C2/C1 in crosswind case.

The solution for angle θ is an inverse solve problem. To solve the inverse problem, firstly we assume wind direction is known, and then we can find out the proposed angle to reach the peak point.
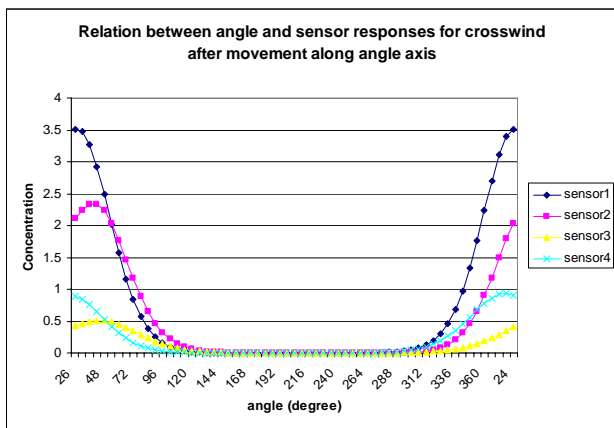

Fig. 5 Relations between angle θ and sensors responses for crosswind case after movement along angle axis

After analysis, the peak point is occurred when the source position is on a line with slope of crosswind direction α and also this line is the tangent of sensor 1. The tangent equation for crosswind direction α of the sensor 1 circle could easily be given by following equations:

$$-\sqrt{\frac{1}{1+\tan^2 \alpha}} \cdot x + \tan \alpha \sqrt{\frac{1}{1+\tan^2 \alpha}} \cdot y = R \qquad (3)$$
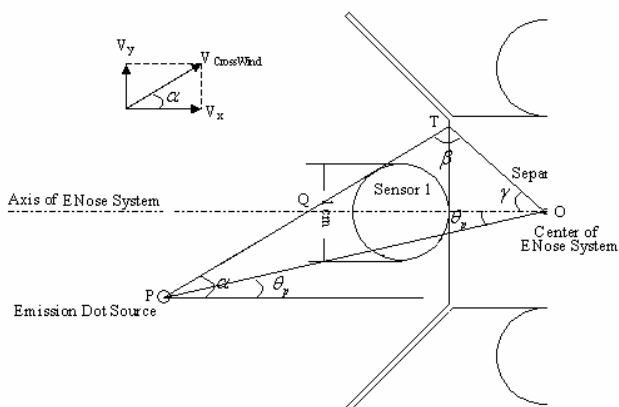
where R is the radius of sensor 1.

Fig. 6 Calculation of angle for peak point

Fig. 6 shows the diagram for calculation scheme for the angle of peak point. P is the proposed source position; O is center of ENose system (origin); T is the intersection point of PT and edge of separator, Q is intersection point of PT and x axis. PT is the tangent with crosswind direction of sensor 1, which has equation as equation (3).

As TO, OQ, QT is known, by simply calculate Euclidean distance

$$d_{X_x X_2} = \left\| X_1 - X_2 \right\|_2 \qquad (4)$$

Here X_1 X_2 could be replaced by TO, OQ, and QT.

Thus, β and γ can be calculated by law of cosines. Also the source position P(x,y) could be rewritten as $P(x, x \tan \theta_p)$. Point P is on a straight line which denoted by equation (3), also ΔOPQ obey all of laws for triangle. A set of equations could be established which looks like following:

$$\begin{cases} -\sqrt{\frac{1}{1+\tan^2 \alpha}} \cdot x + \tan \alpha \sqrt{\frac{1}{1+\tan^2 \alpha}} \cdot x \tan \theta_p = R \\ Cos(\alpha - \theta_p) = \dfrac{d_{PT}^2 + d_{PO}^2 - d_{OT}^2}{2 d_{PT} \cdot d_{PO}} \end{cases} \qquad (5)$$

The second equation in equation set (5) is based on law of cosines. Thus, angle for peak point θ_p can be calculated. Also, the set of the equation are easily to be implemented by computer language.
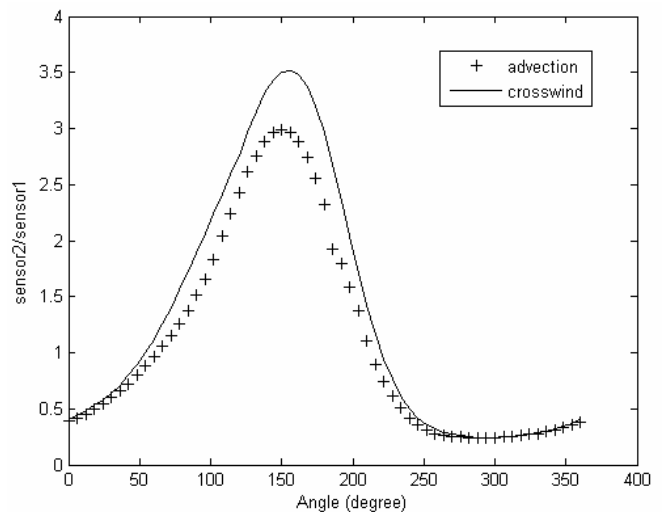

Fig. 7 Comparison of C2/C1 for advection and crosswind situation
We have error at SSE: 0.1499, R-square: 0.9981, Adjusted R-square: 0.998 and RMSE: 0.05128, which are acceptable

Fig. 7 shows the curve for both advection and crosswind situation; obviously they all accord with Gauss distribution and have similar shape. To let $f(\theta)$ be the function for ratio of sensor 2's response to sensor1's response in advection, the

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function $f_c(\theta)$ in crosswind situation has the relation with direction of crosswind α and peak point angle θ_p.

$$f_c(\theta) = \frac{1}{\cos\alpha} f(\theta - (\alpha - \theta_p)) \qquad (6)$$

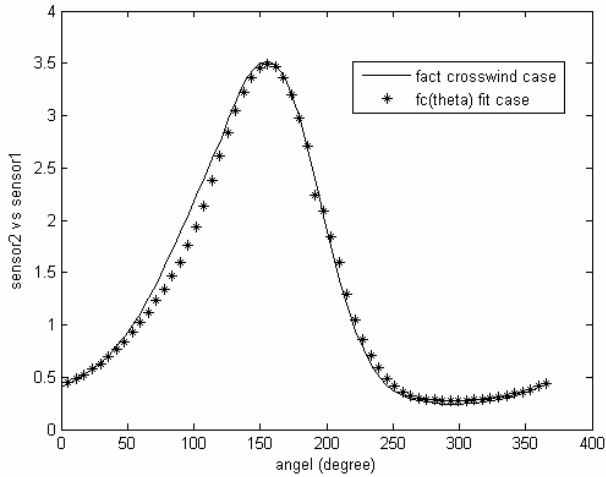Equation (6) is a curve fit function; Fig. 8 shows the fit result.

Fig. 8 Curve fit for fact crosswind case of C2/C1 by $f_c(\theta)$

In this case $\theta = f_c^{-1}(\theta)$ is the way to obtain the direction angle.

Based on the two cases above, we could easily calculate the reverse equation (2) by computer. After the analysis of wind break case, the experimental result is discussed.

IV. NATURAL WIND CASES

In the natural wind cases, we are mainly considering the break wind case, which means that wind breaks in a period then recovers as before. Table I presents the relation of sensor response and time in 5 seconds in both wind break free case and wind break case, where between 0.7s and 1.4s wind breaks.

According to Table I, in both 2 cases, responses of sensors stay steady after 3 seconds. Thus we could treat the response of sensors during wind break as a "noise". To ignore the noise a set of new responses can be derived.

After filtering the noise, simply cut off the response signal between 0.8s and 1.5s, sensors' responses in wind break case almost same as them in wind break free case. Thus for wind break case, we could consider it as a wind break free case, by analyzing a steady responses of sensors.

TABLE I
RESPONSES OF SENSORS FOR BOTH WIND BREAK CASE AND WIND BREAK FREE CASE
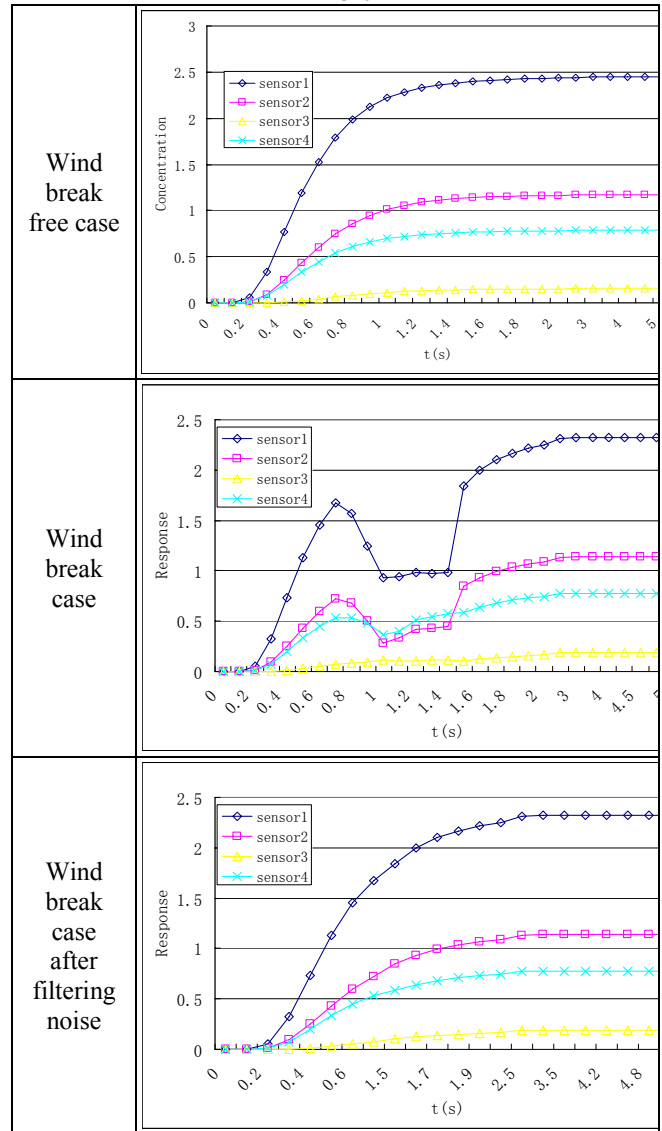
V. EXPERIMENTS AND RESULTS

Experiments are done in both advection and crosswind cases. We set initial concentration of the source is 5000 ppm, advection wind speed V_x=5m/s, crosswind wind speed V_x=3m/s, V_y=1.8m/s. Time is set to 20 seconds.

We give a set of point which has direction angle θ, 0^0, 60^0, 120^0, 180^0, 240^0 and 300^0. The source is then placed on these points one by one, each time start the experiment after the sensors' response recovers to environment.

The result of calculated direction is listed in Table II. The calculated relative error shows in Table III, for the result of direction angle we use range of 360^0 as the style to present the result, which avoids the unary operator.

According to Table III, we have highest error at 60^0 for both advection and crosswind case, that is because the Gauss3 fitting equation has highest error round 60^0, and curve fitting of eq5 also has higher error between 50^0 and 110^0. However,

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the mean relative error for both advection and crosswind cases are acceptable.

TABLE II
EXPERIMENTAL RESULT AND SOURCE DIRECTION

Real direction	Advection Result	Crosswind Result
60^0	59.92^0	61.46^0
120^0	120.63^0	116.38^0
180^0	180.41^0	178.01^0
-120^0	-120.22^0	-116.68^0
-60^0	-59.67^0	-62.81^0
$360^0(0^0)$	$360^0(0^0)$	360.11^0

TABLE III
EXPERIMENTAL RESULT ERRORS

Real direction	Advection Relative Error	Crosswind Relative Error
60^0	0.13%	2.38%
120^0	0.52%	3.11%
180^0	0.23%	1.1%
-120^0	0.12%	2.85%
-60^0	0.55%	4.47%
$360^0(0^0)$	0.0%	0.03%
Mean Error	0.26%	2.14%

VI. CONCLUSION

In this paper, a novel direction detection method bases on single electronic nose system is presented in nature wind situations. The method successfully solves the source direction detection problem in advection, crosswind and wind break cases. The experimental results show that this method is accurate. Additionally, the optimization of this method needs to be done in optimizing the fitting equations for both advection and crosswind situation. To be the continuing research target, the method could be use to locate the odour source and navigate the smell tracking robotics.

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